



Diet in Southern Chile (36°–42°S). A synthesis from the isotopic data

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ABSTRACT

In this paper we present and assess human isotopic data ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) available for Southern Chile. We analyze 24 cases from six different geographical zones, dated 200–1850 AD. This new information allows us to characterize individuals who had different subsistence patterns, social organization and historical trajectories, vis-a-vis phenomena like the adoption of ceramics (150 BC), cultigens (750–1000 AD) and the arrival of Europeans (1550 AD). This is complemented by a regional baseline of 45 archaeological faunal and plant resources.

Based on our results, three dietary patterns can be identified over time (from 1000 to 1850 AD): one oriented towards marine resources, another towards C_3 plants and terrestrial protein, and the last focused on a mixed consumption of C_3 and C_4 plants, complemented by intake of terrestrial and marine protein. These cases show significant intra-zone consistency over time, and high inter-zone variability.

This heterogeneous situation is evident even in synchronous individuals ascribed to the same cultural-historical unit or inhabiting the same geographical macro-zone (valley, coast, islands). It also contrasts with results from adjacent areas to Southern Chile. This highlights the complex diet variability that existed in societies which otherwise appear to be extremely alike in their archaeological record (burials, pottery) and ethnographic features (language, rituals).

1. Introduction

The use of stable isotopes has proved to be an invaluable tool in archaeology for assessing phenomena such as economic strategies, mobility patterns, paleodiet, etc., in different contexts from South America and around the world. In the case of Chile, isotopic studies have concentrated on the Atacama Desert (Tieszen et al., 1992; Knudson and Torres-Rouff, 2009; Torres-Rouff et al., 2012; Pestle et al., 2015; Andrade et al., 2015, 2016; Santana-Sagredo et al., 2015a; King et al., 2018), the Semi-arid North (Becker et al., 2015; López et al., 2015; Alfonso-Durruty et al., 2017), Central Chile (Falabella et al., 2007, 2019; Tykot et al., 2009; Sanhueza and Falabella, 2010, Falabella and

Sanhueza, 2019) and Patagonia (Méndez et al., 2014; Reyes et al., 2012, 2013, 2019). Isotopic data have also been published for Neuquén province in Argentina, immediately east of Southern Chile (Fernández and Panarello, 2001; Della Negra and Novellino, 2002; Gordón et al., 2013, 2018; Gordón and Novellino, 2016; Barberena et al., 2018; Pérez et al., 2019).

So far, very little information has emerged for Southern Chile on human dietary patterns based on stable isotopes studies. This situation is especially remarkable since Southern Chile constitutes (on a continental scale) the southern limit of the prehistoric expansion of agriculture in the Americas (Roa et al., 2018). While to the north, in Central Chile (32°–36° S), agricultural societies were present as from 200/400

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AD (Planella et al., 2014), these practices were virtually absent further south, in Northern Patagonian Channels (42°–47°S), and to the east in Neuquén (36°–41° S), where hunter-gatherers prevailed until the late 19th century (Belmar et al., 2017; Lema et al., 2012). It is therefore of interest to understand how Southern Chile fitted into the temporal and spatial patterns of crop incorporation in relation to these surrounding territories.

Various studies, including isotopic studies, have shown that prehistoric coastal populations in Central Chile did not exploit marine resources intensively (Falabella et al., 2007; Falabella and Sanhueza, 2019). This pattern contrasts with evidence from the Northern Patagonian Channels where full-blown maritime adaptation and diet have been present for the last 6000 years (Massone et al., 2016; Reyes et al., 2019). Following these previous reconstructions of coastal diet, questions remain concerning the diets consumed in Southern Chile from AD 200–1800, in particular considering the apparent diversity of trajectories of different populations of this territory during the last 5000 years in terms of marine exploitation and exploration (Campbell, 2015).

Finally, from the 16th century onwards, Southern Chile displayed a complex social scenario (Bengoa, 2003; Boccara, 2007; Dillehay, 2007) due to the arrival of the Europeans, who introduced new animals, plants and human groups. One aspect of this situation was the emergence of active and successful indigenous resistance down to the present, first to the Spanish Empire and then to the Chilean state. A further aspect was the indigenous expansion from Southern Chile across the Andes into what today is the western territory of Argentina (Neuquén, La Pampa, and Río Negro provinces).

That said, Southern Chile can play a pivotal role in our understanding of processes in Southern South America: the expansion and adoption of agriculture, the development of marine-oriented societies and post-contact indigenous dynamics. In this context, isotopic studies have an important role since they provide evidence about phenomena that are difficult to grasp from the conventional material record and/or by traditional methodologies. This paper aims to fill the lacuna on dietary information that has characterized Southern Chile, contributing the first archaeological isotopic database for the region. Stable isotope analysis of carbon and nitrogen were carried out on 24 individuals, dated from 200 to 1850 AD, in order to reconstruct their dietary patterns. This is accompanied by the isotopic characterization of 45 animal and plant resources from archaeological sites over the same time span. We are aware that this is still a limited sample, both in terms of space and time, and any attempt to draw definite or overarching conclusions would be premature.

2. Regional setting

Southern Chile (Fig. 1) is a territory of ~111,400 km² lying between 36°S and 42°S, in a narrow strip (maximum width 260 km) trapped between the Andes Mountains and the Pacific Ocean. In geomorphological terms, from west to east it consists of a coastal plain (and off-lying islands), the Coastal Range (up to 1500 masl), the Central Valley or Intermediate Depression, the *Montaña* or Precordillera (between 600 and 1000 masl), and the Andes Cordillera (with maximum elevations generally around 3000 masl) (Börgel, 1983).

Following Aldunate (1989), the area can be divided into two sectors at 39.42°S. The northern sector is characterized by a Csb climate (Sarricolea et al., 2017), with warm, dry summers lasting for four months, and rainy winters; this climate is shared with areas like northwestern Iberia and Pacific Coast United States. This sector has deciduous and sclerophyllous vegetation and the presence of *Araucaria* (*Araucaria araucana*) forests in areas over 900 masl (Gajardo, 1994); the majority of the area falls into the Mediterranean macrobioclimate unit (Luebert and Pliscoff, 2006). In contrast, the southern sector is marked by a Cfb climate, lacking a dry season and with higher rainfall; it is comparable with the United Kingdom, Ireland, France and New Zealand. Here deciduous broad-leaved vegetation coexists with

evergreens, forming part of the Temperate macrobioclimate unit.

Southern Chile exhibits a long and varied sequence of hunter-gatherer groups from around 14,500 cal BP (Dillehay, 1997; Dillehay et al., 2008; Adán et al., 2016; Núñez et al., 2016), or perhaps even 18,500 cal BP (Dillehay et al., 2015). The earliest appearance of pottery in the northern sector is dated to around 150 BC (Adán et al., 2016; Marsh, 2017) and by 350 AD it is well distributed (Adán and Mera, 2011). The antiquity of pottery in the southern sector is not yet clearly established, although by the end of the first millennium AD it seems to have been ubiquitous north of the Chacao Channel. The first dated evidence of crops, however, does not appear until the 8th century AD (Campbell et al., 2018; Roa et al., 2018), in the form of beans (*Phaseolus vulgaris*) and quinoa (*Chenopodium quinoa*) which are C₃ plants. Crops become a generally ubiquitous resource in the northern sector from 1000 AD onwards. This date also coincides with the first evidence of maize (*Zea mays*), the only C₄ plant that reached Southern Chile in prehistoric times. It must be understood that hunting, gathering and fishing were not abandoned with the adoption of agricultural practices. The 16th century is marked by the arrival of Europeans, who introduced new C₃ plants like wheat (*Triticum* sp.), barley (*Hordeum vulgare*) and legumes into Southern Chile. From 1550, the Spaniards founded several towns and forts throughout this territory, however in 1598 a momentous *Reche* native revolt drove them back to north of the Biobío and Laja rivers. *Reche* was the all-encompassing name used by the native inhabitants of Southern Chile to refer to themselves during the 17th and 18th centuries; it was then replaced by *Mapuche*, which is the ethnonym still in use (Boccara, 2007). During the 17th and 18th centuries, the Spaniards were able to found only two new towns in the southern sector of Southern Chile. This led effectively to the existence of an independent native country between the Biobío and Laja rivers in the north and the Cruces and Valdivia rivers in the south, bearing a frontier relationship with Spanish territory for the remaining colonial period, until 1818 AD, and then with the independent Republic of Chile. It was not until the 1860s, in a primarily military operation that spanned almost three decades, that the Chilean government invaded and finally occupied the entire Mapuche territory of Southern Chile.

In archaeological terms, the prehistoric sequence described above has been subdivided into periods (Adán et al., 2016). For the purposes of this paper, the appearance of pottery around 150 BC falls into the Late Archaic period (2000 cal BC - 350 cal AD). It is followed by the Early Ceramic period (350 AD - 1000 AD) in which the Pitrén cultural complex is the principal known cultural-historical unit, albeit the existence of other complexes is still poorly described. The Late Ceramic period (1000 AD - 1550 AD) is represented in the northern sector of Southern Chile by the El Vergel complex, although some diagnostic traits of the Pitrén complex are present until 1200 AD. In the southern sector, meanwhile, characteristics typical of Pitrén appear to continue until the arrival of the Europeans in the mid-16th century.

Both Pitrén and El Vergel respond to archaeological labels defined to describe a certain group of material culture traits, while *Reche* and *Mapuche* are concepts derived from ethnohistorical and ethnographic research. These distinctions and their use here do not invalidate the historical – and almost certainly ethnic and social – continuity that existed and still exists between these different research units.

In this context, the use of stable isotopes in archaeological research in Southern Chile to approach aspects of human diet has been very limited (not to mention for mobility, paleoclimatic and paleoecological reconstructions). The first analyses ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in bone collagen) were performed as recently as the 2010 decade (Massone et al., 2012a). The reasons for this are probably related to the poor preservation of human organic remains – including bones and teeth – in a territory characterized by acid soils and high seasonal rainfall, and the resulting assumption that stable isotope studies are not a viable methodology in most research projects carried out in Southern Chile. We hope to show, however, that in sufficiently well-preserved cases, stable isotopes analysis can play an important role in our comprehension of larger social

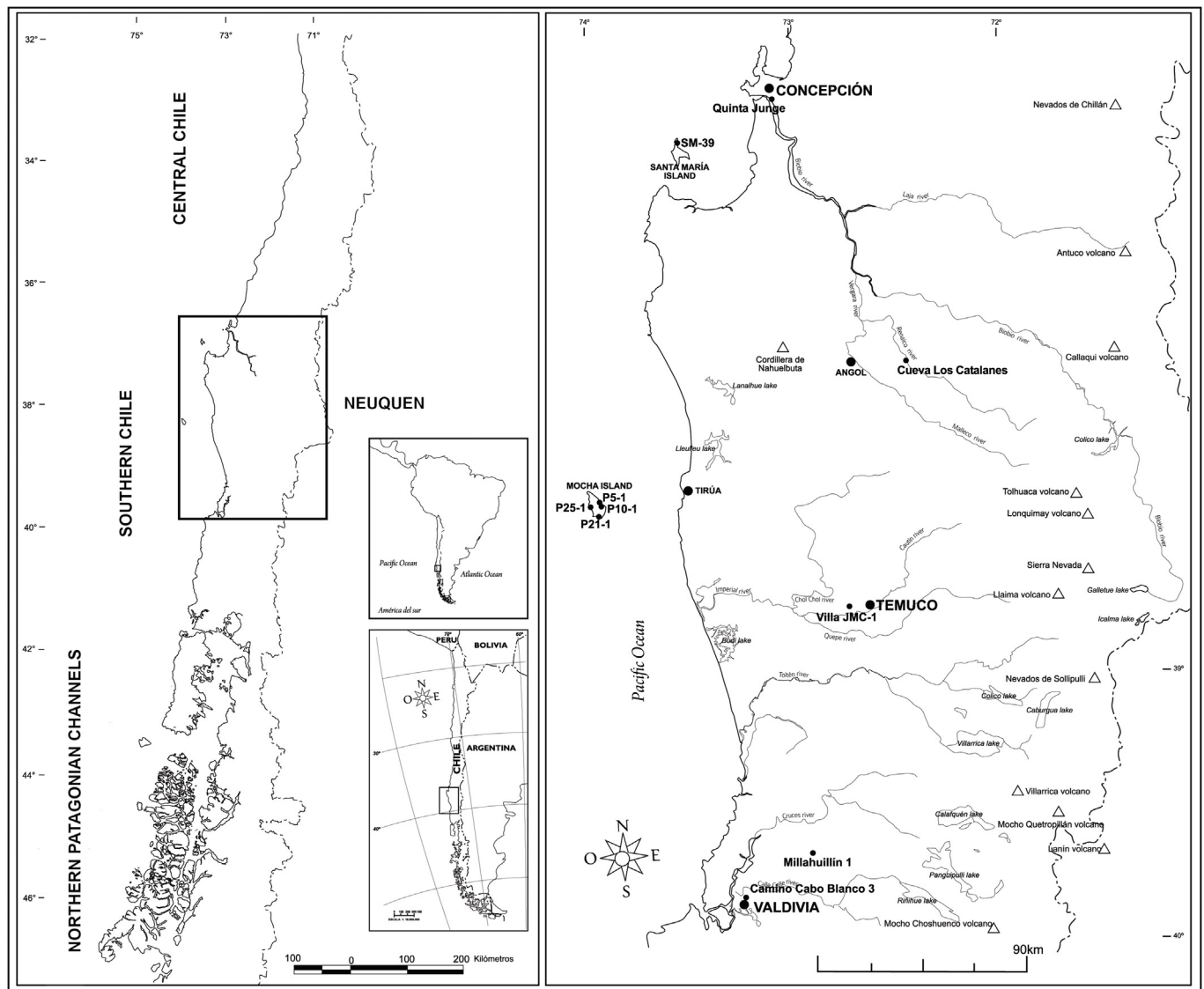


Fig. 1. Location of archaeological sites in Southern Chile with human remains analyzed in this paper.

and historical phenomena, as well as at the level – almost biographical – of specific individuals.

3. Materials and methods

3.1. Data

In this study, 24 individuals were included for stable isotope analysis of carbon (bone and dentine collagen, enamel and bone apatite) and nitrogen (bone and dentine collagen). The samples come from different geographical zones including insular ($n = 12$), coastal ($n = 2$), and Central Valley ($n = 10$) contexts, with no cases for the Precordillera or the Andes Cordillera. All but five belong to the northern sector of Southern Chile.

The remains were recovered from 10 different archaeological sites, excavated almost exclusively during the last 10 years (Table 1), as part of research projects, Cultural Resource Management studies or fortuitous findings. They constitute the full set of information available today for stable isotopes in humans for Southern Chile. Because of the small size of our sample universe, its dispersed geographical nature, and its lack of chronological continuity in a single zone, we took a regional approach for our research. A brief description of each

geographical zone, sites and contexts is provided below:

3.1.1. From insular contexts

- 1) Santa María Island (n = 5), SM-39 site (Massone et al., 2009, Massone et al., 2012a). This site is located on the coast near Puerto Norte, on a steep slope that overlooks El Inglés Bay to the south. Nine individuals were recovered at this site, and stable isotope analysis was performed on individuals 6, 1, 9, 3, and 7 (as numbered in the original publications). In the present study they are identified as individuals #1, 2, 3, 4 and 12 respectively. They date to the Late Archaic Period (n = 1), the Early Ceramic Period (n = 3), and the El Vergel complex (n = 1).
- 2) Mocha Island (n = 7), sites P5-1, P10-1, P21-1, and P25-1 (Vásquez and Sánchez, 1993; Constantinescu, 1997; Sánchez, 1997; Quiroz and Sánchez, 2005; Campbell, 2020). These sites are located at different points on the island's coastal plain. Two individuals can be ascribed to the Pitrén Complex (individuals #5 and 6 in our study), based on their dates and associated material culture. They come from a disturbed burial area distant from nearby domestic sites (site P10-1). The remaining 5 individuals (#7, 13, 14, 15 and 16 in our study) can be ascribed to the El Vergel complex and come from

Table 1
Stable isotopes results for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ and from human samples including bone collagen ($\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}_{\text{col}}$), and bone or enamel apatite ($\delta^{13}\text{C}$) (ordered by age). (ECP = Early Ceramic Period).

#	Chronological block	Laboratory Sample Number	Site	Age	Sex	Anatomical Unit	Cultural ascription	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}_{\text{col}}$	$\delta^{13}\text{C}_{\text{ap}}$	C/N ratio	^{14}C year BP	Error $\pm$	Median calibrated date AD	Project*
1	1	Beta 310945	SM-39	30–39 years	Male	Tooth	Late Archaic	-12.1	21.7	-	-	1850	30	210	1
2	2	Beta 310948	SM-39	18 $\pm$ 6 months	Indeterminate	Tooth	ECP	-14.2	19.8	-	-	1580	30	529	2
3	2	Beta 310947	SM-39	Indeterminate	Indeterminate	Tooth	ECP	-13.7	19.3	-	-	1550	30	565	1
4	2	Beta 310949	SM-39	25–35 years	Female	Ulna	ECP	-13.8	19.1	-	-	1480	30	619	2
5	3	AA109584	P10-1	40–45 years	Male	Metacarpal	Pitrén	-14.7	11.2	-8.5	3.3	1169	26	935	3
6	3	AA110796	P10-1	35 years	Male	Phalange	Pitrén	-11.4	16.7	-8.0	3.5	1143	31	946	3
7	3	AA110795	P5-1	18 $\pm$ 6 months	Indeterminate	Tooth	El Vergel	-16.2	19.3	-9.6	3.4	1021	27	1090	4
8	3	AA110999	Cueva de los Catalanes	Adult	Indeterminate	Scapula	ECP	-19.2	7.7	-11.9	3.4	972	23	1096	5
9	3	UGAMS 23784	Villa JMC-1	25–45 years	Male?	Tooth	Pitrén	-17.1	6.8	-9.1	3.5	930	25	1167	6
10	3	UGAMS 23782	Villa JMC-1	20–24 years	Female?	Tooth	Pitrén	-18.4	9.4	-9.4	4.1	920	25	1177	6
11	3	UGAMS 23783	Villa JMC-1	17–25 years	Indeterminate	Tooth	Pitrén	-16.7	6.9	-11.1	3.3	910	25	1185	6
12	4	Beta 310946	SM-39	Newborn	Indeterminate	Temporal	El Vergel	-13.7	21.7	-	-	620	30	1354	1
13	4	AA109586	P21-1	6 months	Indeterminate	Tooth	El Vergel	-15.7	-	-10.1	ND	563	25	1417	7
14	4	AA109583	P25-1	14–17 years	Male	Phalange	El Vergel	-14.0	12.5	-9.1	3.4	516	24	1435	3
15	4	AA109585	P5-1	Adult	Female	Metacarpal	El Vergel	-14.7	13.8	-9.9	3.3	506	25	1439	3
16	4	AA110797	P21-1	Adult	Indeterminate	Rib	El Vergel	-15.4	13.0	-9.9	3.4	443	22	1471	7
17	5	UGAMS 23781	Millahuillin 1	30–34 years	Female	Tooth	Reche	-18.1	8.0	-10.2	3.2	400	20	1513	8
18	5	UGAMS 23780	Millahuillin 1	16–20 years	Indeterminate	Tooth	Reche	-16.7	8.7	-10.2	3.3	340	20	1557	8
19	5	UGAMS 27081	Camino Cabo Blanco 3	Adult	Male?	Tooth	Reche	-14.8	9.1	-5.7	3.2	350	25	1559	9
20	5	UGAMS 23778	Millahuillin 1	20–24 years	Female?	Tooth	Reche	-17.0	8.8	-11.0	3.2	360	20	1560	8
21	5	UGAMS 23779	Millahuillin 1	16–20 years	Indeterminate	Tooth	Reche	-18.1	8.0	-10.8	3.2	380	20	1563	8
22	5	UGAMS 31679	Quinta Junge	20–35 years	Female	Femur	Reche	-14.9	11.4	-10.3	3.2	270	20	1659	10
23	5	AA111000	Cueva de los Catalanes	Adult	Indeterminate	Temporal	Mapuche	-20.9	6.2	-13.6	3.3	178	23	1801	5
24	5	UGAMS 31678	Quinta Junge	20–35 years	Female?	Fémur	Mapuche?	-19.3	7.7	-11.3	3.3	160	20	1846	10

* 1: FAIP 24-03-192 (48). 2: FAIP 24-03-192 (61). 3: FONDECYT 1921129. 4: NSF BCS-0956229. 5: FONDECYT 11150397. 6: FONDART 21511-2. 7: FONDECYT 1990027. 8: FONDECYT 1130730. 9: GORE-MOP Mejoramiento ruta Cabo Blanco - Las Marias. 10: Construcción Templo de Concepción, Iglesia de Jesucristo de los Santos de los Últimos Días.

Table 2
Results of stable isotope analyses of carbon and nitrogen on archaeological crops and bone and teeth from faunal resources.

#	Laboratory Sample Number	Site	Sample Type	Taxa	Anatomical Unit	Type of resource	$\delta^{13}\text{C}$ col	$\delta^{15}\text{N}$ col	$\delta^{13}\text{C}$ ap	C/N ratio	^{14}C year BP	Error $\pm$	Median calibrated date AD	Reference
1	AA 111539	Cueva de los Catalanes	Bone	<i>Canis lupus familiaris</i>	Right femur	Terrestrial	-19.6	9.4	-10.4	3.3	1547	24	569	This paper
2	AA 111538	Cueva de los Catalanes	Bone	<i>Lama guanicoe</i>	Right tibia	Terrestrial	-21.5	6	-11.3	3.3	1527	24	590	This paper
3	UGAMS 27387	Cueva de los Catalanes	Bone	<i>Camelidae</i> sp.	Second phalange	Terrestrial	-23.3	12.2	-13.8	5.0	1410	25	662	Campbell et al. (2018)
4	UGAMS 27386	Cueva de los Catalanes	Seed	<i>Phaseolus vulgaris</i>	1 cotyledon	C3 Crop	-24.1	1.7	-	13.4	1300	25	745	Campbell et al. (2018)
5	AA 111536	P22-1	Bone	<i>Pudu pudu</i>	Humerus	Terrestrial	-21.9	9.7	-9.8	3.3	1273	42	805	This paper
6	AA 108925	P22-1	Bone	<i>Pudu pudu</i>	Horn	Terrestrial	-21.3	29.2	-9.7	3.5	1220	24	865	This paper
7	UB 29290	P23-2	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-9.2	6.4	-	23.1	1108	28	990	This paper
8	AA 108935	P25-1	Bone	<i>Camelidae</i> sp.	Diaphysis	Terrestrial	-20.4	11.7	-10.4	3.4	1055	25	1022	This paper
9	AA 108936	P25-1	Bone	<i>Pudu pudu</i>	Phalange	Terrestrial	-21.6	13.1	-11.4	3.4	1053	27	1025	This paper
10	AA 108923	P22-1	Bone	<i>Ouaridae</i> sp.	Rib	Marine	-11.6	16.3	-6.9	3.4	1033	24	1065	This paper
11	UB 24526	P5-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-9.7	9.1	-	21.5	992	30	1095	This paper
12	AA 108933	P25-1	Bone	<i>Pudu pudu</i>	Humerus	Terrestrial	-22.8	8.1	-10.6	3.5	944	24	1150	This paper
13	AA 108938	P29-1	Bone	<i>Camelidae</i> sp.	Diaphysis	Terrestrial	-20.6	8.5	-10.2	3.5	821	24	1249	This paper
14	UB 24523	P5-1	Seed	<i>Chenopodium quinoa</i>	14 Seeds	C3 Crop	-27.9	11.0	-	21.7	816	27	1250	This paper
15	UB 24525	P5-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-9.0	4.9	-	23.4	796	25	1263	This paper
16	AA 108932	P25-1	Bone	<i>Camelidae</i> sp.	Epiphysis	Terrestrial	-21.1	9.9	-12.0	3.5	758	23	1286	This paper
17	UB 29286	P12-1	Bone	<i>Camelidae</i> sp.	Metapodium	Terrestrial	-20.3	10.5	-	3.2	753	27	1260	This paper
18	AA 108928	P23-2	Bone	<i>Camelidae</i> sp.	Diaphysis	Terrestrial	-21.4	7.5	-10.9	3.5	740	23	1296	This paper
19	UB 29282	P12-1	Bone	<i>Camelidae</i> sp.	4° carpal bone	Terrestrial	-19.8	8.7	-	3.2	744	32	1298	This paper
20	UB 24524	P5-1	Seed	<i>Chenopodium quinoa</i>	77 Seeds	C3 Crop	-28.6	7.6	-	20.7	718	22	1316	This paper
21	AA 108937	P29-1	Bone	<i>Camelidae</i> sp.	Diaphysis	Terrestrial	-20.7	9.9	-10.4	3.5	654	23	1344	This paper
22	UGAMS 27385	Cueva de los Catalanes	Seed	<i>Zea mays</i>	Cob Fragment	C4 Crop	-10.5	12.4	-	80.4	660	20	1344	Campbell et al. (2018)
23	UB 29284	P12-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-9.8	5.7	-	19.9	656	27	1345	This paper
24	UB 29288	P25-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-10.2	6.4	-	21.6	661	30	1345	This paper
25	UB 29287	P25-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-9.6	4.0	-	19.3	644	35	1346	This paper
26	AA 108930	P25-1	Bone	<i>Camelidae</i> sp.	Metapodium	Terrestrial	-21.4	9.2	-10.4	3.5	687	33	1346	This paper
27	UB 24528	P5-1	Bone	<i>Camelidae</i> sp.	Carpal bone	Terrestrial	-20.9	15.4	-	3.3	668	26	1346	This paper
28	AA 108921	P22-1	Bone	<i>Camelidae</i> sp.	Carpal bone	Terrestrial	-18.3	9.4	-7.4	3.4	709	23	1347	This paper
29	UB 29289	P23-2	Seed	<i>Phaseolus vulgaris</i>	1 Cotyledon	C3 Crop	-24.4	2.3	-	16.4	679	25	1348	This paper
30	UB 24529	P5-1	Bone	<i>Camelidae</i> sp.	3° Phalange	Terrestrial	-21.1	10.8	-	3.3	683	26	1348	This paper
31	AA 108939	P31-1	Bone	<i>Camelidae</i> sp.	Phalange	Terrestrial	-21.2	10.8	-12.0	3.5	706	23	1349	This paper
32	AA 108934	P25-1	Bone	<i>Camelidae</i> sp.	Humerus	Terrestrial	-20.7	11.0	-11.6	3.5	703	23	1350	This paper
33	AA 108929	P23-2	Bone	<i>Camelidae</i> sp.	Phalange	Terrestrial	-19.1	8.8	-9.8	3.4	700	23	1351	This paper
34	AA 108920	P5-1	Bone	<i>Camelidae</i> sp.	Molar	Terrestrial	-20.7	9.9	-13.6	3.3	611	23	1394	This paper
35	UB 26216	P5-1	Bone	<i>Camelidae</i> sp.	Phalange	Terrestrial	-21.2	6.9	-	3.2	605	26	1397	This paper
36	AA 108924	P22-1	Bone	<i>Camelidae</i> sp.	Phalange	Terrestrial	-21.3	9.0	-9.9	3.4	572	23	1413	This paper
37	UB 26214	P5-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-10.0	4.9	-	22.2	552	26	1421	This paper
38	NZA 28271	El Arenal 1	Bone	<i>Gallus gallus</i>	-	Terrestrial	-19.9	2.6	-	3.2	510	30	1437	Storey et al. (2008, 2013)
39	NZA 28272	El Arenal 1	Bone	<i>Gallus gallus</i>	-	Terrestrial	-19.5	3.5	-	3.2	506	30	1438	Storey et al. (2008, 2013)
40	AA 108922	P22-1	Bone	<i>Camelidae</i> sp.	Molar	Terrestrial	-21.7	10.7	-10.9	3.3	453	23	1463	This paper
41	UB 29283	P12-1	Seed	<i>Zea mays</i>	1 Grain	C4 Crop	-9.6	3.3	-	24.7	453	28	1465	This paper
42	AA 108931	P25-1	Bone	<i>Camelidae</i> sp.	Talus	Terrestrial	-20.1	7.7	-11.6	3.5	428	23	1481	This paper
43	AA 108926	P23-2	Bone	<i>Camelidae</i> sp.	Phalange	Terrestrial	-21.2	6.6	-11.6	3.4	400	23	1527	This paper

(continued on next page)

Table 2 (continued)

#	Laboratory Sample Number	Site	Sample Type	Taxa	Anatomical Unit	Type of resource	$\delta^{13}\text{C}$ col	$\delta^{15}\text{N}$ col	$\delta^{13}\text{C}$ ap	C/N ratio	^{14}C year BP	Error $\pm$	Median calibrated date AD	Reference
44	AA 111537	Cueva de los Catalanes P23-2	Bone	<i>Pudu puda</i>	Tibia	Terrestrial	-21.6	6.6	-11.3	3.2	242	37	1750	This paper
45	AA 108927		Bone	<i>Pudu puda</i>	Molar p3	Terrestrial	-21.2	8.1	-11.1	3.5	243	23	1752	This paper

burials – disturbed and undisturbed – interspersed within larger domestic areas.

3.1.2. From coastal contexts

- 3) Lower Biobío river (n = 2), Quinta Junge site (Andrade et al., 2018; Andrade et al., 2020). This site is located in the urban area of the modern city of Concepción, and is associated with the Catholic mission “San José de la Mocha”. This was established in 1685 AD to receive the native inhabitants of Mocha Island after its forced depopulation in 1685–1687; the mission was finally abandoned in the mid-late 19th century. The dated individuals for whom isotope analysis has been carried out are related with the founding and closure of the mission (individuals #22 and 24 in our study).

3.1.3. From Central Valley contexts

- 4) Lower Renaico river (n = 2), Cueva de los Catalanes site (Menghin, 1959-60; Berdichewsky, 1968; Andrade, 2018; Campbell et al., 2018). This site, located near Mininco, consists of a cave of 33 m length and 5 m maximum height. Excavations have yielded several disarticulated human bones dispersed throughout the site stratigraphy and in different and non-contiguous excavation units. Radiocarbon dates have allowed the identification of at least two individuals, one from the Late Ceramic period and the other from the Historical period immediately before the Chilean invasion of Southern Chile (individuals #8 and 23 in our study respectively).
- 5) Mid-reaches of the Cautín river (n = 3), Villa JMC-1 site (Mera and Munita, 2008; Munita et al., 2011; Mera, 2014; Mera et al., 2015; Musaubach et al., 2015). This is a Pitren Complex cemetery which, based on the dates, represents a late moment of Pitren, in coexistence with communities that already displayed an El Vergel material culture. The burial offerings provide remarkable, quite unique items for a Pitren context, such as high-purity copper earrings, oyster shell and lutite beads, obsidian, and maize (in the form of residues attached to ceramic sherds). Stable isotope analysis was carried out for three individuals (individuals #9, 10 and 11 in our study).
- 6) Mid-reaches of the Cruces River (n = 4), Millahuillín 1 site (Musaubach et al., 2015; Silva, 2015; Munita et al., 2016; Solari, 2016). This site was accidentally discovered during forestry activities; its central sector is an indigenous cemetery. The recovered material culture and dates allowed its ascription to the Late Ceramic Period and early historical times. The individuals have offerings of pottery and sheep. Stable isotope analyses were carried out for four individuals (individuals #17, 18, 20 and 21 in our study).
- 7) Lower Cruces-Valdivia river (n = 1), Camino Cabo Blanco 3 site (Mera and Munita, 2016). This one-individual burial was discovered – and damaged – as part of a road construction. Although the excavation was limited to the burial, it seems that it was set in or adjacent to a larger domestic area of Late pre-Hispanic and Early Historical characteristics, based on the surface material recovered as well as the dating of the individual. This is individual #19 in our study.

As mentioned above, these 24 individuals span from the 3rd to the 19th century AD. They therefore allow us to approach the Archaic populations at the moment of pottery adoption, and then to move through the first ceramic groups properly speaking (Pitren complex and others), to the first clearly agricultural communities (El Vergel complex). Finally, the Historical period cases provide information about the different social scenarios marked by the European arrival in both colonial and native contexts.

In order to contextualize the human isotope information, we have considered isotopic data from local plant and animal resources available to these populations during the last 2000 years. A total of 45

Table 3

Descriptive statistics for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from faunal resources together with C_3 and C_4 plants. (for faunal terrestrial resources only cases with C/N ratios between 2.9 and 3.6 were included; cases #3, 6, 38 and 39 as in Table 2 were excluded from statistics calculations).

Type of Resource	Terrestrial (n = 27)		Marine (n = 1)		C_3 Crop (n = 4)		C_4 Crop (n = 9)	
	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
Mean	−20.9	9.4	−11.3	16.3	−26.3	5.7	−9.7	6.3
SD	0.9	2.1	0	0	2.3	4.4	0.5	2.8
Max	−18.3	15.4	−11.3	16.3	−24.1	11.0	−9.0	12.4
Min	−22.8	6.0	−11.3	16.3	−28.6	1.7	−10.5	3.3

archaeological samples from Southern Chile were considered in this study for stable isotope analysis of carbon and nitrogen in plants and bone and dentine collagen from animals (Table 2; Table 3). Three different crops were included: *Z. mays* (n = 9), *P. vulgaris* (n = 2) and *Ch. quinoa* (n = 2). Zooarchaeological samples included bones from the Camelidae family (n = 22, including one specimen of *Lama guanicoe*), *Pudu puda* (n = 6), *Gallus gallus* (n = 2), *Canis lupus familiaris* (n = 1) and *Otariidae* sp. (n = 1). These samples come solely from archaeological sites: P5-1, P10-1, P12-1, P21-1, P22-1, P23-2, P25-1, P29-1, and P31-1 (on Mocha Island) (n = 37), Cueva de los Catalanes (n = 6) and El Arenal (n = 2). This isotopic baseline is biased towards island contexts, and specifically Mocha Island, due to sample availability. Still, they are coincident with the values theoretically expected for each taxon, so they can be used to approach these aspects in Southern Chile. In the future, further studies are required in order to complement this baseline and contrast these results.

3.2. Methodology

We are aware that our human sample set is quite small (n = 24). For this reason, no inferential statistics were carried out in this work and analysis was limited to descriptive statistics.

Human samples were sent by each research team to different laboratories for stable isotope analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ and radiocarbon dating. Stable isotopes of carbon and nitrogen were analyzed in dentine and bone collagen, while inorganic stable isotopes of carbon were analyzed in enamel and bone apatite. SM-39 samples (n = 5) were analyzed in Beta Analytic, Mocha Island (n = 7) and Cueva de los Catalanes (n = 2) in the laboratories of the University of Arizona, and finally Millahuillín 1 (n = 4), Villa JMC-1 (n = 3), Quinta Junge (n = 2), and Camino Cabo Blanco 3 (n = 1) were analyzed at the University of Georgia. Radiocarbon dates were calibrated using the southern hemisphere curve SHCal13 (Hogg et al., 2013) with the OxCal v4.3.2 program (Bronk Ramsey, 2009); dates were not corrected for the Marine Reservoir Effect (MRE).

All the laboratories considered here use international standards (IAEA) when calibrating their isotope results, following similar methodologies for collagen extraction and bioapatite pre-treatment (removing secondary carbonates with acetic acid), making the inter-laboratory comparisons trustworthy. In particular, for the analysis of carbonates, the international standards for calibration used at the University of Arizona were NBS-18 and NBS-19. The University of Georgia uses the internal standards A1296 and Fisher calcium which have been calibrated using the international standard NBS-19.

The radiocarbon dates obtained from SM-39 could potentially be affected by the MRE, since – as will be discussed in the following section – the dated individuals show high $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. It is quite possible that Mocha Island individuals are also affected by this effect, but to a lesser degree. Unfortunately, there are no detailed studies on the MRE for these particular areas of Chile, and therefore it is not possible to correct the dates using a known local variation (ΔR) of the MRE. For this reason, we treated these dates with care in the paper, bearing in mind that they could potentially be biased by the MRE.

To analyze the present data, one strategy would be to rely on the

traditional cultural-historical periods (Archaic, Early Ceramic, Late Ceramic, Historical) along with the cultural complexes and ethnic groups associated with them (Pitrén, El Vergel, Reche, Mapuche). However, the small size of our sample and its geographical dispersion precludes a thorough and sound description for any of them. For that reason, we preferred a regional approach to assess the data. At the same time, the use of those units conveys the risk of reifying them, to the point of overshadowing interesting differences within and between them.

In consideration of these problems, we estimated that a better strategy was to segregate the individuals analyzed here into five different “chronological blocks” (Fig. 2). In this way we will be able to compare contemporary individuals that inhabited different areas of Southern Chile regardless, for the moment, of their cultural-historical affiliations. These blocks were designed in consideration of the chronological distribution of our current 24 samples, and therefore they can be completely re-defined in the future when more results become available or for different research objectives. We also tried to ensure that no block was so chronologically ample that it resulted in mixing of disparate evidence and, at the same time, that each one captured a certain key phenomenon.

The first block is 100–375 AD (275 years) and marks an early moment of pottery adoption in Southern Chile, along with the presence of only C_3 wild plants; the second is 375–700 AD (325 years) and relates to the full development of the Early Ceramic period societies (Pitrén Complex and contemporary cultures) with no evidence of any cultivated crops; the third is 850–1275 AD (425 years), showing the transition from the Early Ceramic to the Late Ceramic period, the earliest evidence of C_3 crops (beans and quinoa) and then maize from 1000 AD onwards; the fourth is 1275–1500 AD (225 years), characterized by the full development of Late Ceramic period societies (El Vergel complex and contemporary cultures) together with evidence of C_3 and C_4 cultivated crops; and finally the fifth block is 1500–1950 AD (450 years), belonging to the Historical period starting in 1550 AD, which includes the arrival of Europeans and new C_3 crops, and several distinct inter-ethnic contacts and frontier phenomena.

4. Results and discussion

4.1. Diet in Southern Chile by chronological blocks

The results of the human stable isotope analyses are presented in Table 1. Most of the samples considered here present good collagen preservation based on their good C/N ratios (DeNiro, 1985; Ambrose, 1990). However, one individual was discarded from further analysis in relation to $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}$ due to the high C/N ratio found (individual #10, Villa JMC-1). Another individual (#13, P21-1) has no results for collagen $\delta^{15}\text{N}$, but does for $\delta^{13}\text{C}_{\text{coll}}$. Based on this, only bioapatite results obtained for them were considered.

Unfortunately, the laboratory in which the SM-39 analyses were carried out did not give information on the C/N ratios before 2016, as they were not frequently requested by the users of that lab (Beta Analytic personal communication 2017). However, since the data are consistent with the location and surrounding geography (marine

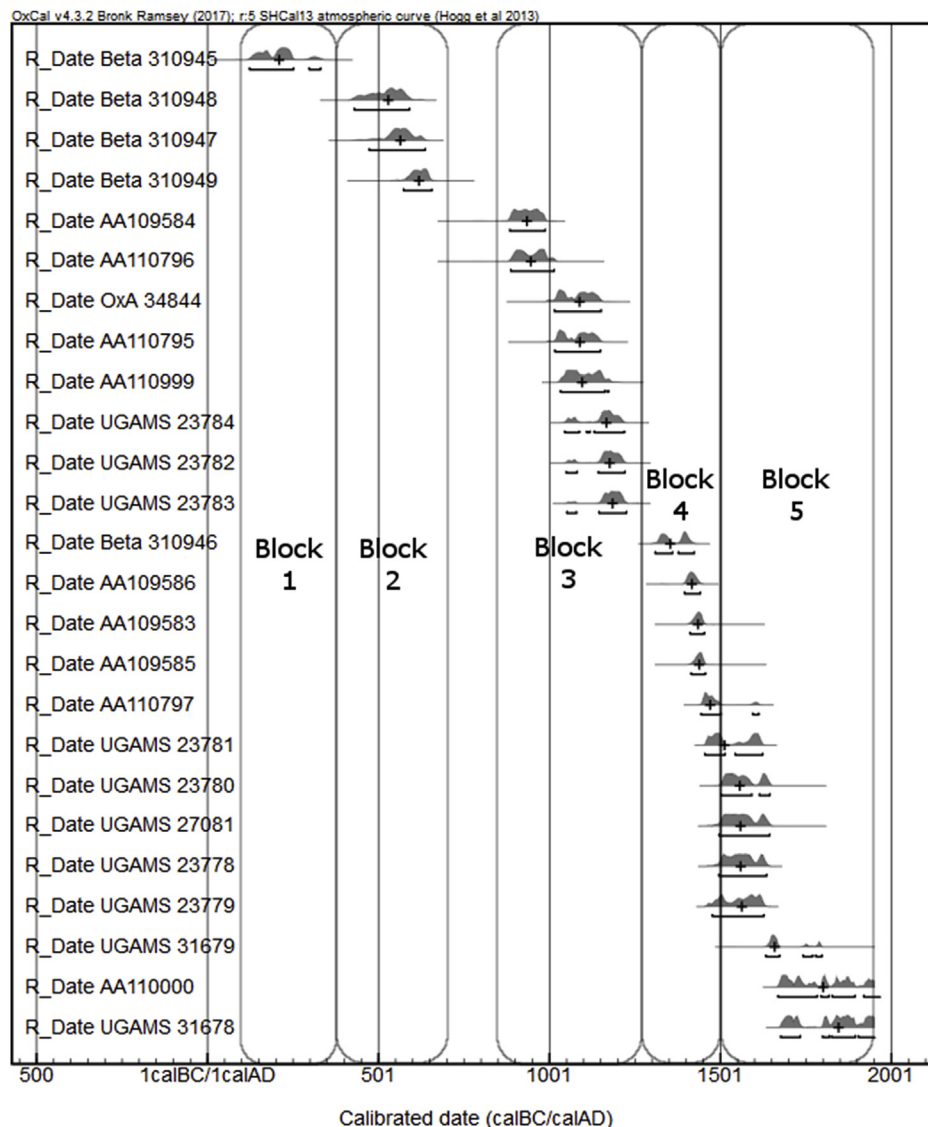


Fig. 2. Calibrated dates and “chronological blocks”.

ecosystem), we decided to include them for analysis and interpretation.

Following the chronological blocks outlined above, the results for the earliest block, from 100 to 375 AD, is represented by only one individual from Santa María Island (individual #1). This individual shows high $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ values (Fig. 3a), higher than those observed for marine resources.

The second block, from 375 to 700 AD, includes three individuals, also from Santa María Island (individuals #2, 3 and 4). They follow a similar pattern to that presented by the previous individual, with enriched composition of ^{13}C (average $-13.9 \pm 0.9\text{‰}$ for $\delta^{13}\text{C}_{\text{col}}$) and ^{15}N ($20.0 \pm 1.2\text{‰}$ for $\delta^{15}\text{N}$) (see Fig. 3a). The only sample associated with an infant (individual #2, aged around 18 ± 6 months), also presents values characterized by high $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$.

The next block, 850–1275 AD, includes seven individuals: three from Mocha Island (individuals #5, 6 and 7), one from Cueva de los Catalanes (individual #8) and two from Villa JMC-1 (individuals #9 and 11). Individuals #6 and #7 show the highest values for $\delta^{15}\text{N}$ in bone collagen with 16.7‰ and 19.3‰ , respectively, plotting close to the values reported for marine resources (Fig. 3b; Fig. 4). However, the $\delta^{13}\text{C}_{\text{col}}$ value of individual #7 is lower (-16.2‰) than individual #6 (-11.4‰). This could be related to the fact that the former is an infant aged around 18 ± 6 months, and its ^{15}N enrichment can probably be associated with breastfeeding. In contrast, individual #5 shows lower

values for $\delta^{13}\text{C}_{\text{col}}$ (-14.7‰) and $\delta^{15}\text{N}$ (11‰) relating to a rather mixed diet that may have included terrestrial and marine resources. At the same time, Mocha Island individuals show relatively high $\delta^{13}\text{C}_{\text{ap}}$ in their enamel and bone apatite, strongly suggesting the ingestion of C_4 plants, in this case most likely maize. In contrast, the values for the individuals from Cueva de los Catalanes and Villa JMC-1 fall closer to those of terrestrial and C_3 resources, and very close to each other.

The fourth block, 1275 to 1500 AD, is represented by 5 individuals: one from Santa María Island (individual #12) and three from Mocha Island (individuals #14, 15 and 16). Following a similar pattern to that of the first block, the Santa María Island individual is highly enriched in ^{13}C and ^{15}N . However, this individual is a newborn baby who probably died soon after birth, so the results are likely to reflect the diet of its mother. The Mocha group shows a similar composition to individual #5 from the previous chronological block, with intermediate $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ values (lower than Santa María Island, but higher than Cueva de los Catalanes and Villa JMC-1) suggesting a mixed diet incorporating terrestrial and marine resources.

Finally, the 1500–1950 AD block is composed of eight individuals: four from Millahuillín 1 (individuals #17, 18, 20 and 21), one from Camino Cabo Blanco 3 (individual #19), two from Quinta Junge (individuals #22 and 24), and one from Cueva de los Catalanes (individual #23). During this period, the $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ values observed for

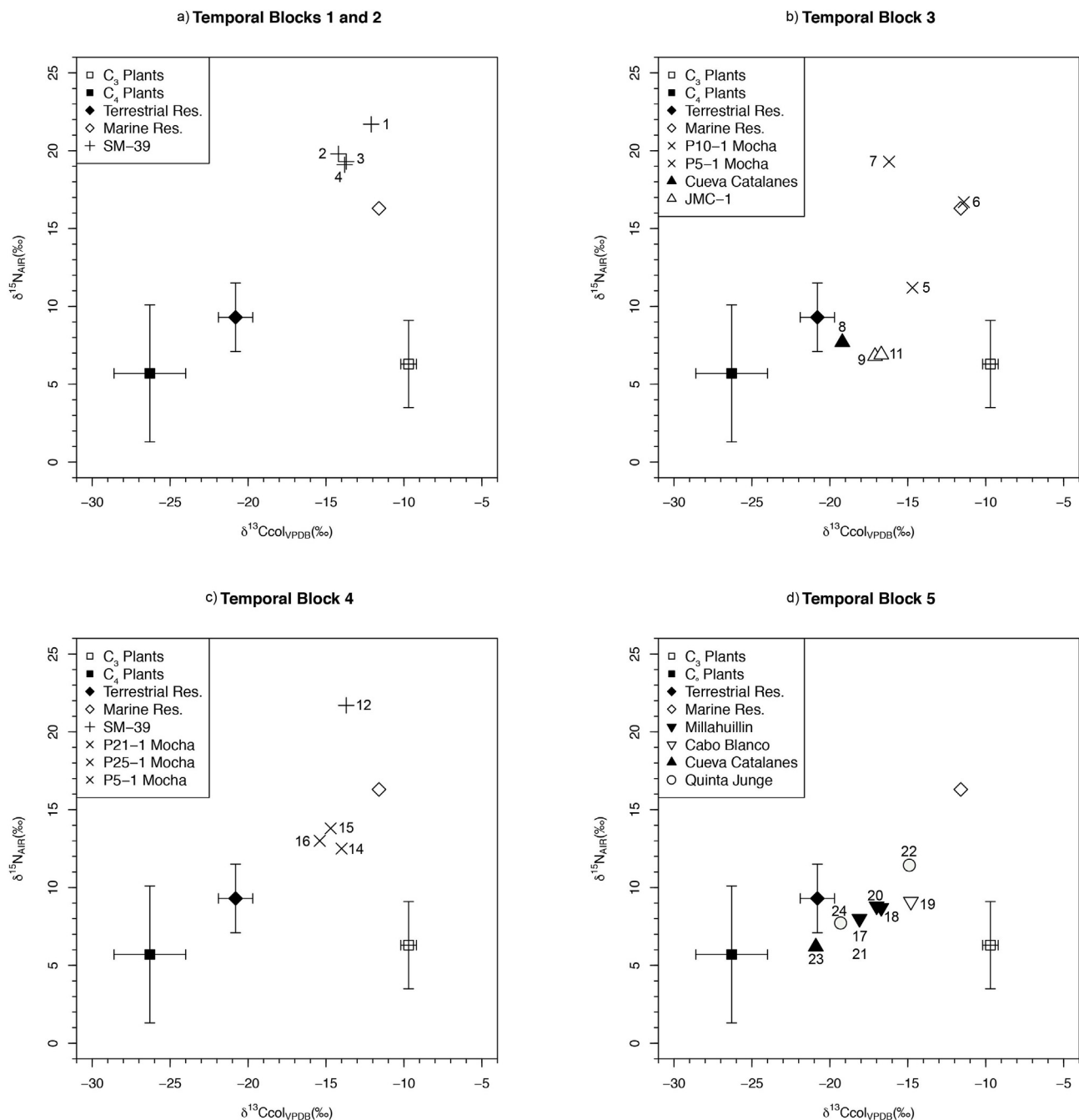


Fig. 3. Bivariate plots showing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from bone collagen human samples for each chronological block (numbers as in Table 1) as well as archaeological faunal and plant resources means and SD by type of resource (as calculated in Table 3).

these individuals are relatively low compared to those from Santa María and Mocha islands. Individual # 23 shows the most depleted composition in both ^{13}C and ^{15}N of all of the individuals analyzed for this block. The same is reflected in the $\delta^{13}\text{C}_{\text{ap}}$ enamel and bone apatite values, which are the lowest observed in the whole sample analyzed here, particularly individual #23 with a minimum of -13.6‰ . Although during this temporal block the tendency is to observe mainly terrestrial diets, individual #22 shows a similar pattern to the Mocha Island individuals from the fourth block, suggesting a mixed marine-terrestrial diet based on the $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ values (-14.9‰ and 11.4‰). This is consistent with the geographical location of Quinta Junge close to the coast, however it is more plausible that this individual belongs to the Mocha Island native people who were relocated to the San José Mission in 1685–1687 AD. In fact, individual #24, also

from Quinta Junge, shows $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (-19.3‰ and 7.7‰) lower than individual #22. Individual #24 on the other hand resembles the isotopic composition of individual #8 from Cueva de los Catalanes, and individuals #17 and #21 from Millahuillín. It is worth noting that individual #24 dates to a later moment (AD 1846) than individual #22 (AD 1659).

4.2. Diet in Southern Chile by geographical zone

4.2.1. For insular contexts

The archaeological record for Santa María Island shows initial exploitation of marine resources and wild C_3 plants (Massone et al., 2009, 2012a). Then, from 1000 AD onwards, an important change occurs with the inclusion of cultivated C_3 plants (quinoa) and the transfer of

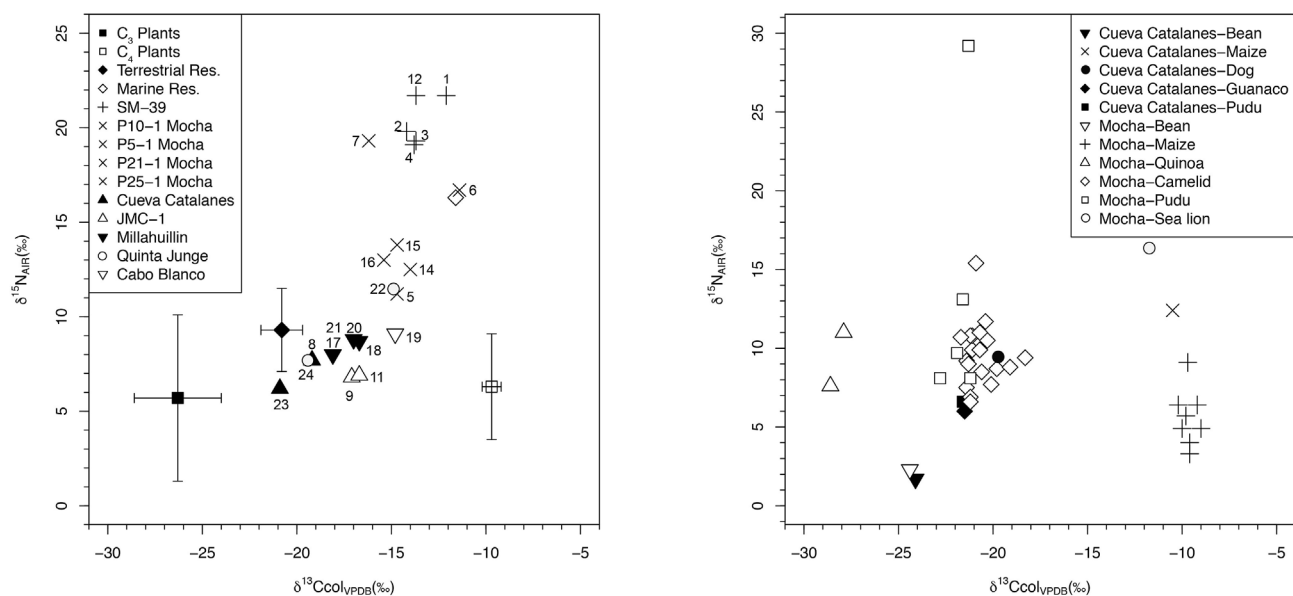


Fig. 4. Bivariate plots showing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from all bone collagen human samples for each chronological block as well as archaeological faunal and plant resources means and SD by type of resource (left) (as calculated in Table 3), and $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from each archaeological faunal and plant resource (right).

camelids from the mainland to the island (Massone et al., 2008; Silva, 2010). So far, the only evidence of maize on this island belongs to historical pollen obtained from environmental columns; no macro-remains have ever been recovered here (Massone et al., 2012b). Thus, the stable isotope information gathered from the Santa María Island individuals analyzed here is in agreement with the archaeological evidence, showing a strong marine diet over a period lasting for a millennium. Questions remain on whether these individuals consumed maize. The C₄ signal could be hidden by the marine diet in the carbon collagen composition of the Santa María group (Lee-Thorp, 2008). In order to have a better estimate on this aspect, stable carbon isotope analyses from enamel or bone apatite are needed.

In the case of the newborn baby (individual #12), its nitrogen isotope values would reflect the mother's isotopic signal since it does not show any increase in $\delta^{15}\text{N}$ values related to breastfeeding; this infant probably died soon after birth. On the other hand, the infant aged 18 ± 6 months (individual #2) was probably already weaned and consuming an adult diet, since we do not observe trophic level enrichment in comparison to the contemporary adult individuals.

The archaeological evidence from Mocha Island shows the endemic presence of C₃ wild plants as well as birds, marine mammals, fish and shellfish before 800 AD (Rojas and Cardemil, 1995; Sánchez et al., 2004; Quiroz and Sánchez, 2005; Goicovich and Quiroz, 2008). From 800 to 1000 AD, animals imported from the mainland appear in the archaeological record – camelids, *P. puda* (pudu), *Lycalopex* sp. (fox), *Leopardus guigna* (kodkod), and *Galictis* sp. (grison). In addition, from 1000 AD onwards there is evidence of C₃ (quinoa and beans) and C₄ (maize) cultivated crops, both as micro and macro-remains (Roa et al., 2015; Roa et al., 2018; Godoy, 2018). Most of the Mocha Island individuals analyzed here, from a period lasting around 500 years, seem to reveal a mixed diet that combined both terrestrial (animals, C₃ and C₄ plants) and marine resources, although the latter in a smaller proportion. In this sense, the archaeobotanical and zooarchaeological record of Mocha Island are in accordance with the isotope results obtained for the individuals analyzed here, supporting the ingestion of C₃ and C₄ crops as well as terrestrial and marine resources.

However, there are two exceptions to this type of diet: individuals #6 and 7. The first is from site P10-1 and shows a more marine diet than that of the other Mocha Island individuals (#5, 14, 15 and 16), based on the higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. In fact, this is most noticeable since individual #6 is chronologically contemporary to individual

#5, and both come from the same site; yet the latter shows evidence of a mixed terrestrial-marine diet that is almost coincident with that of later individuals (#14, 15 and 16). One hypothesis is that individual #6 was a “foreigner” originally from a place with a more marine diet. Another possibility is that around 1000 AD, the population of Mocha Island experienced a change from a largely marine to a mixed terrestrial-marine diet, and that this shift is reflected in these two contemporary individuals (#6 and #5). The isotope signal of individual #7, an infant of 18 ± 6 months, would suggest breastfeeding, based on its $\delta^{15}\text{N}$ enrichment and rather low $\delta^{13}\text{C}$ value compared to the rest of the Mocha Island group.

Isotopic composition for archaeobotanical remains on Mocha Island reflects a clear differentiation (as expected) in $\delta^{13}\text{C}$ between C₃, including quinoa and beans, and C₄ (maize) plants (Fig. 4b). It is worth noting that one quinoa sample (#14 in Table 2) as well as one maize sample (#11 in Table 2) show $\delta^{15}\text{N}$ values that are higher than the other specimens, reaching maxima of 11‰ and 9‰, respectively. The $\delta^{15}\text{N}$ of this particular quinoa sample is surprisingly close to that of individual #5 from Mocha Island. Based on the enriched $\delta^{15}\text{N}$ composition observed in these crops, it is possible to argue that fertilizers were probably playing a role in the agricultural practices of Mocha Island around AD 900–1250, coincident with our third chronological block (850–1275 AD). We suggest these crops were fertilized, based on their high $\delta^{15}\text{N}$, as it is unlikely that the aridity effect/watering regimes could impact crops in this region of Southern Chile where rainfall occurs frequently and there are plenty of water sources on the island (including streams and ponds). Experimental studies on modern maize and beans show how the use of manure can drastically change the nitrogen isotope composition of crops, leading to an enrichment in $\delta^{15}\text{N}$ (Szpak et al., 2012, 2014). For this reason, we argue that the use of fertilizers in C₃ and C₄ crops probably explains the high $\delta^{15}\text{N}$ values presented here.

The camelids of Mocha Island, as well as the small herbivore pudu, show a consistent C₃ diet based on their $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{13}\text{C}_{\text{ap}}$ values (Fig. 4b; Fig. 5b). However, one camelid (#27) presents an isotopic composition enriched in $\delta^{15}\text{N}$, similar to that observed for the only sea lion sample (#10) from the same island (camelid $\delta^{15}\text{N} = 15.4\text{‰}$; sea lion $\delta^{15}\text{N} = 16.3\text{‰}$). A similar situation occurs for one pudu (#9) with a nitrogen isotope value of 13.1‰. However, surprisingly, we observe an extraordinary case for another pudu (#6) showing a $\delta^{15}\text{N}$ of 29.2‰ (Fig. 4b). The C/N ratio for this individual falls in the range expected

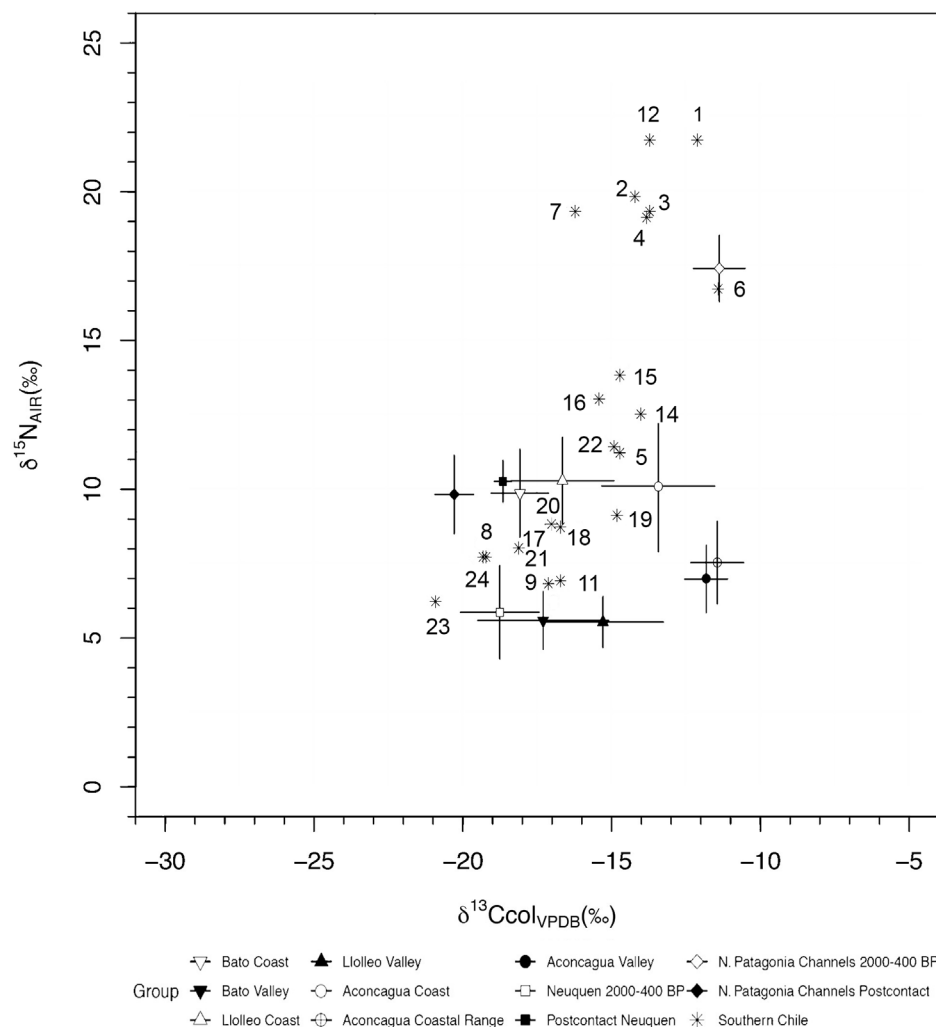


Fig. 5. Bivariate plots showing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from bone collagen human samples (numbers as in Table 1) as well as means and SD for archaeological individuals from Central Chile (Bato, Lilloe, Aconcagua), Northern Patagonian Channels, and Neuquén (as in Table 4).

for good collagen preservation (3.5). As this $\delta^{15}\text{N}$ value is extremely high, and does not correlate to any of the observed values from other fauna and botanical sources analyzed here, it is not possible to explain nor associate it with the evidence obtained so far from Mocha Island. It has been reported that archaeological sheep in Neolithic Orkney (Scotland) consumed seaweed, increasing their $\delta^{15}\text{N}$ (Schulting et al., 2017). However, the nitrogen isotope values for Orkney's sheep only reach maxima close to 9.6‰, very different to the Mocha Island pudu (#6). It is possible this pudu consumed a diet highly enriched in ^{15}N botanical resources on Mocha Island. We do not discard the possibility that physiological aspects might be playing a role in the enrichment observed, as reported for herbivores in East Africa (Ambrose, 1991). However, the Africa study is also related to conditions of aridity and limited water sources, which again is not the case for Mocha Island. Without a doubt, future research needs to be carried out on this individual in order to understand its extremely enriched ^{15}N composition. As for camelid #27 and pudu #9, showing higher $\delta^{15}\text{N}$ values compared to the other individuals (clearly distinct from pudu #6), it is possible that they accessed plant resources enriched in ^{15}N such as seaweed, fertilized crops or wild vegetation. So far, there are no stable isotope studies on the wild vegetation of the island, so important information on isotopic composition is lacking for Mocha Island, hindering better understanding of the diet of these herbivores.

4.2.2. For coastal contexts

Quinta Junge has clearly differentiated domestic and burial areas. The artefactual and ecofactual evidence recovered in the survey is scarce, and no clear, direct inference can be made about the foods consumed (Andrade et al., 2018; Andrade et al., 2020). However, historical documents about life in the mission are available; they show that meat was provided to the mission, and that it also had small-scale local horticultural production which included beans, wheat, barley and potatoes (Goicovich and Quiroz, 2008; Hanish, 1974). This information is in agreement with the isotope data observed for individual #24, with low $\delta^{13}\text{Ccol}$ and $\delta^{13}\text{Cap}$ values strongly suggesting the ingestion of C_3 resources, and terrestrial fauna (low $\delta^{15}\text{N}$). However, the diet reconstruction for individual #22 contrasts with the historical information and differs from individual #24 in that it shows higher $\delta^{13}\text{Ccol}$ and $\delta^{15}\text{N}$. It is worth noting that there is a chronological difference between the two Quinta Junge individuals of around 200 years, implying there could have been changes in the food provided at the mission over time moving towards a terrestrial- C_3 based diet. Still, the stable carbon and nitrogen isotope values for individual #22 resemble those observed for individual #5 from Mocha Island, probably ingesting marine resources and perhaps a small proportion of C_4 resources. It is important to consider that the two individuals analyzed represent two different moments in the mission's history; while the later individual's isotopic information seems to reflect what the documents indicate, the earlier individual appears to portray the diet of the forcibly displaced Mocha

Island population.

4.2.3. For Central Valley contexts

The zooarchaeological evidence from Cueva de los Catalanes shows a strong association between the isotope data and the fauna remains obtained at the site (Zúñiga, 2018). For instance, *L. guanicoe* is the most represented taxon throughout the 1500 year-long occupational sequence at the site which relates to the terrestrial diet observed for individuals #8 and #23. Terrestrial fauna is complemented by other species such as *P. puda*, *Lycalopex* sp. *Myocastor coypus* (nutria), *Conepatus chinga* (skunk), *C. lupus familiaris*, and undetermined rodents, marsupials, chiropterans and amphibians. In the upper layers there is presence of European animals such as *Capra hircus* (goat), *Bos taurus* (cow) and *Equus caballus* (horse). The archaeobotanical record shows the presence of C₃ crops (quinoa and beans) from 750 AD as part of the occupation dated to the Early Ceramic Period, then maize for the Late Ceramic occupation, and finally wheat for the post-1550 AD layers (Roa et al., 2018). The isotope results tend to support these findings, since both individuals from this cave show a terrestrial C₃-oriented diet; however, in the case of the earlier individual this would be related with New World plants, whereas the latter probably consumed Old World species. The lack of a C₄ signal in the earlier individual is remarkable, given that maize seems to have been available throughout Southern Chile; however, this individual was recovered from a layer assigned to the Early Ceramic Period of the site. Thus, although they present similarities, these two individuals reveal exploitation of quite different resources.

Stable isotope results for the fauna of Cueva de los Catalanes show a similar composition to those observed for Mocha Island (Fig. 4b), with the exception of the camelid and pudu individuals enriched in ¹⁵N from the island. A dog sample (#1) was analyzed for Cueva de los Catalanes showing a terrestrial-C₃ diet resembling the human diet reported at the site.

Two crop samples were analyzed for this cave, beans (#4) and maize (#22). The bean sample shows a similar isotope composition to that reported for Mocha Island. The maize sample shows high $\delta^{15}\text{N}$ (12.4‰), slightly higher than the values for the quinoa and maize observed in Mocha Island. Based on this, it is likely that this crop was also fertilized, as proposed for Mocha Island.

Villa JMC-1 and Millahuillín 1, given their context in prehistoric cemeteries, present rather limited archaeological data compared to the above sites. In the case of Villa JMC-1, an important feature is the presence of C₃ plants (quinoa), while the only evidence of maize comes from micro-remains (Mera, 2014; Musaubach et al., 2015). No faunal evidence is available for burials at this site. The three almost contemporary individuals analyzed fit this evidence with heavy reliance on terrestrial resources and C₃ plants, although there was probably low ingestion of C₄ resources. At Millahuillín 1 the archaeobotanical evidence points to the presence of Old World C₃ crops such as barley and wheat, and also of New World C₃ grains such as *Madia sativa* (madi) and *Bromus* sp. (mango); no maize was recovered at the site (Musaubach et al., 2015; Silva, 2015; Solari, 2016). Therefore, it is in accordance with the data obtained from the stable isotope composition.

Finally, in the case of Camino Cabo Blanco 3 the absence of archaeobotanical and zooarchaeological remains makes it impossible to assess the site data in relation to the stable isotope results obtained. However, the Camino Cabo Blanco 3 individual (#19) presents the most enriched in ¹³C composition for biopate. This high value in $\delta^{13}\text{C}_{\text{Cap}}$ observed for this individual would probably suggest considerable ingestion of C₄ resources in the diet. However, this enrichment is not as high in the isotope composition of collagen-carbon, with a value of -14.8‰ . Populations in northern Chile with heavy reliance on C₄ resources, such as Pica 8, show averages of $\delta^{13}\text{C}_{\text{Ccol}}$ and $\delta^{13}\text{C}_{\text{Cap}}$ of $-11.1 \pm 2.4\text{‰}$ and $-5.9 \pm 2.6\text{‰}$ respectively (Santana-Sagredo et al., 2015b). If individual #19 was consuming a high amount of C₄ resources, it would necessarily show a more positive value for $\delta^{13}\text{C}_{\text{Ccol}}$,

which is not the case. Since Camino Cabo Blanco 3 is located in an area close to the coast and a wetland, it is likely that the $\delta^{13}\text{C}_{\text{Cap}}$ could be altered by diagenesis. Nevertheless, the $\delta^{13}\text{C}_{\text{Ccol}}$ value for this individual still supports the possibility of C₄ ingestion, but in moderate quantity. The ¹³C enrichment in carbon collagen for this individual clearly does not come from the ingestion of marine resources, as its $\delta^{15}\text{N}$ suggests rather a terrestrial diet (9.1‰). This case resembles the dietary patterns observed for coastal individuals from Central Chile (Falabella and Sanhueza, 2019), who did not rely on marine resources although they lived by the coast. This individual shows evidence of dental wear and ingestion of carbohydrates which could be related to moderate ingestion of maize and other C₃ grains. So far it cannot be distinguished whether oral health problems are related to Old World or New World C₃ grains.

4.3. Diet reconstruction in Southern Chile

These results raise several points for consideration. When the information obtained across time and geographical regions is compared, it is surprising to observe that Santa María and Mocha islands show such different dietary patterns, even though they are both islands and located not far from one another (150 kms). While consumption of marine resources predominates in the former, with crops and terrestrial animals probably a secondary aspect in their diets, in Mocha Island the situation is reversed. It is striking that these differences persisted for at least 500 years. Moreover, as Mocha is further from the mainland (35 kms) than Santa María (12 kms), one might expect a more marine-oriented diet in the more isolated and oceanic island.

A second aspect is related to the individuals from Villa JMC-1, where despite their dates (1166–1184 AD) and the fact that maize was available regionally from at least 1000 AD, no major contribution of maize is observed in either of the diets or the contexts. This situation can be extended to the earliest individual (#8) from Cueva de los Catalanes (1100 AD). One hypothesis is that certain communities remained more conservative and therefore more attached to the practices of the Early Ceramic period, delaying adoption of this new crop.

The contexts at Villa JMC-1 and Cueva de los Catalanes show similar isotope compositions for carbon and nitrogen to Millahuillín 1, despite their geographical, chronological and contextual differences. However, this resemblance is reduced when it is remembered that the latest individuals from Millahuillín 1 and Cueva de los Catalanes were probably accessing mostly to Old World C₃ crops such as wheat, while the earliest individuals in Villa JMC-1 and Cueva de los Catalanes consumed local C₃ crops and wild plants. In fact, it is surprising to observe the rapid adoption of Old World C₃ crops by the local communities in Millahuillín 1.

The Camino Cabo Blanco 3 burial is remarkable for its strong C₄ signal, contrasting dramatically with the three sites mentioned above, and in spite of its proximity to and contemporaneity with the Millahuillín burials. Still, the possibility of diagenesis, outlined above for the Camino Cabo Blanco 3 individual, must also be considered here.

Quinta Junge presents a heterogeneous situation in itself. On the one hand, the earliest individual (1658 AD) aligns quite well with the Mocha Island dietary pattern – most probably this was one of the inhabitants of the island relocated in the 17th century (cf. Andrade et al., 2020). In contrast, the later individual (1844 AD) shows a C₃ diet closer to that of Villa JMC-1 and Millahuillín 1, and the earliest individual from Cueva de los Catalanes (1100 AD), so probably ingested either local or Old World C₃ crops.

Another aspect of interest is the difference in weaning practices documented for Santa María and Mocha islands. While in the former an infant aged 18 ± 6 months already displayed an adult diet, an equivalent individual in the latter was still being breastfed.

Our results therefore indicate the presence of at least three discrete dietary patterns, from 1000 to 1800 AD:

- oriented towards marine resources, represented by Santa María Island individuals and to a certain point by Mocha Island individual #6;
- oriented towards a mixture of C₃ and C₄ plants combining terrestrial and marine protein, represented by Mocha Island individuals and Quinta Junge individual #22. This excludes the presumed breast-feeding infant from Mocha Island (individual #7);
- oriented towards C₃ plants and terrestrial protein, represented by individuals at Cueva de los Catalanes, Villa JMC-1, Millahuillín 1, Camino Cabo Blanco 3 and by Quinta Junge individual #24. This is the most heterogenous group, in consideration of its wide range of $\delta^{13}\text{C}$ values (from -20.9 to -14.8).

4.4. Southern Chile and its macro-regional context

The above results need to be discussed in a broader perspective, in order to understand how this new information fills the lacuna in Southern Chile in terms of diet reconstructions based on stable isotopes analysis in the context of Southern South America (Fig. 5). In order to do this we have compared the results obtained here with isotopic data from the adjacent regions to Southern Chile: Central Chile to the north (Falabella et al., 2019); the Northern Patagonian Channels to the south (Reyes et al., 2019); and the province of Neuquén in Argentina to the east (Gordon et al., 2018; Pérez et al., 2019) (Table 4).

Island and coastal individuals from Southern Chile (excluding Quinta Junge individual #24) show a much more ^{15}N -enriched diet than those of Central Chile (including the coast and Central Valley) dating from 200 to 1500 AD. In fact, even the Southern Chile island and coastal individuals with the lowest $\delta^{15}\text{N}$ values (Mocha Island individual #5 and Quinta Junge individual #22) resemble the most ^{15}N -enriched coastal Llolleo individuals (Falabella et al., 2019; Falabella and Sanhueza, 2019).

In turn, Mocha Island individuals with high $\delta^{15}\text{N}$, together with all the Santa María Island individuals, show a similar composition to that observed for the Northern Patagonian Channels. However, there is a difference in the $\delta^{13}\text{C}$ values between island samples of Southern Chile versus the Northern Patagonian Channels ones. This could be due to the ingestion of different marine resources or species.

These results seem to indicate that in Southern Chile there was a new starting point for a clear approach towards marine resource exploitation and consumption, which extended southwards to the southern end of the Patagonian channels, contrasting with the peculiar situation of Central Chile in this respect.

When individuals from Southern Chile are compared with those from the Aconcagua groups of Central Chile (1000–1450 AD), we observe a marked difference in $\delta^{13}\text{C}$ with values around -12‰ that contrast with $\delta^{13}\text{C}$ values in Southern Chile around and below -15‰ . On this basis we may suggest that populations of Southern Chile did not develop important reliance on maize consumption, despite its

widespread archaeobotanical presence – as macro and micro remains – from 1000 AD. In fact, the third dietary pattern outlined above for Southern Chile is rather similar to that of Central Chile's Bato and Llolleo groups (200–1200 AD), which have been characterized as horticulturists of C₃ and C₄ plants (Planella et al., 2014). One hypothesis is that in Southern Chile, in contrast to Central Chile, C₃ resources – crops and wild plants – remained the staple resources, while maize might have had a more restricted use (for instance, in feasts and special occasions). However, we have to consider also the small size of our current sample, since isotope analysis has yet to be carried out on individuals from populations that might have had a higher reliance on maize (for example, Central Valley late El Vergel groups).

Finally, the diversity of dietary patterns in Southern Chile contrasts with the situation in Neuquén, where studies have shown a strict pattern of terrestrial protein and C₃ plants in a time span that extends from 3000 BC to the 18th century AD (Gordón et al., 2018; Pérez et al., 2019). In fact, this is very similar to the results for Millahuillín 1 individuals #17 and 21, Cueva de los Catalanes individual #8 and Quinta Junge individual #24. At the same time, in this case it must be remembered that it is difficult to discriminate or propose, from isotopic data alone, whether these Southern Chile cases correspond to hunter-gatherers (as is the case in Neuquén) or to C₃ agriculturalists. Additional archaeological evidence would be required to support either of these claims. The situation became even more complex from the 16th century with the arrival of Old World C₃ plants such as wheat and barley.

5. Conclusions

Over the last 2000 years, no single diet characterized the Early Ceramic Period, Late Ceramic Period or the Historical period in Southern Chile. Considerable heterogeneity occurred within the region, and also when the data are compared to those of neighboring regions such as Central Chile, Northern Patagonian Channels, and Neuquén. This variability is even observed between populations that have been identified as ascribed to the same cultural-historical unit. For example, the El Vergel individuals at Santa Maria and Mocha islands show substantial differences in diet, despite their similarities in material culture and their known ethnohistoric adscription to the broad Mapudungun-speaking Reche groups. Furthermore, these two cases – the only two that offer a more extended diachronic perspective – display quite consistent diets over time. (see Tables 3 and 4)

Another very important aspect to highlight is the emphasis on, and persistence of, the consumption of local resources. This is reflected in the fact that maize, despite its presence in the archaeological contexts, apparently did not assume an important role in diet. Nonetheless, this conclusion may be biased by the small size and the nature of our sample, consisting mostly of island individuals. These areas, like any coastal zone, present the challenge of discriminating between terrestrial C₄ resources (maize) and marine resources.

Further lines of research are required to obtain a more complete picture of human diet using stable isotope studies. First of all, more samples are needed, but also more resources have to be measured in order to obtain a robust baseline. In other words, analysis of human remains is informative but it needs to be associated with the ecological context of the study area.

Analysis must also be extended to include bioapatite as a tool for assessing certain phenomena, for example for evaluating the introduction of maize in coastal and island environments. Studies to estimate the MRE are also required.

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Table 4

Descriptive statistics for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from archaeological individuals from Central Chile (Bato, Llolleo, Aconcagua), Northern Patagonian Channels, and Neuquén (only cases with C/N ratios between 2.9 and 3.6 were included).

Context	$\delta^{13}\text{C}$	SD	$\delta^{15}\text{N}$	SD
Bato Coast	-18.1	1.0	9.8	1.5
Bato Valley	-17.3	2.2	5.6	1.0
Llolleo Coast	-16.6	1.7	10.3	1.5
Llolleo Valley	-15.3	2.0	5.5	0.9
Aconcagua Coast	-13.4	1.9	10.1	2.2
Aconcagua Coastal Range	-11.4	0.9	7.5	1.4
Aconcagua Valley	-11.8	0.7	7.0	1.1
Neuquen 2000–400 BP	-18.7	1.3	5.8	1.6
Neuquen Postcontact	-18.6	0.3	10.2	0.7
Northern Patagonian Channels 2000–400 BP	-11.4	0.9	17.4	1.1
Northern Patagonian Channels Postcontact	-20.3	0.7	9.8	1.3

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